

FIRST ROW d-BLOCK ELEMENTS – TRANSITION METAL ELEMENTS

Write the symbols and electronic configurations for each of the first row d-block elements. Remember the energetically favourable configurations for Cr and Cu – exceptions.

What is a '**transition element**'?

- An element with an **incomplete d sub-level** of electrons
- The first row d-block elements have incomplete **3d sub-levels**
- **EXCEPTIONS**
 - Zn $[\text{Ar}] 3d^{10} 4s^2$ Zn^{2+} $[\text{Ar}] 3d^{10}$ both have a full 3d sub-level
 - Sc $[\text{Ar}] 3d^1 4s^2$ Sc^{3+} $[\text{Ar}]$
 - Scandium is not considered a transition element because its common oxidation state, +3, has no d block electrons.
 - (Strictly speaking the metal is a transition element but the compounds with the Sc^{3+} ion, are not.)

Typical (characteristic) properties of transition metals (d-block elements):

- Variable Oxidation States
- Complex Ion Formation
- Coloured Complexes
- Catalytic Properties

VARIABLE OXIDATION STATES (what you have considered “charges” until now).

- When ions are being formed, the electrons are FIRST removed from the 4s sub-level before the 3d sub-level
- When electrons are removed, the remaining electron levels move closer to the nucleus because there are now more protons than electrons – when this occurs the 3d drops to a lower level than the 4s (remember, the 4s is lower than the 3d in atoms which is why we fill the 4s before we fill the 3d).
- All the d-block elements will lose 4s electrons to form the 2+ oxidation state. Chromium and copper (only have 1 4s electron) but will easily lose 1 electron from the 3d sub-level to also form a 2+ oxidation state.
- After the 4s electrons are removed, some 3d electrons can be removed, allowing the formation of some +3 and +4 oxidation states in the transition elements
- The +4 ions are rare – they will strongly attract molecules and ions to them so they will not be found free as ions but covalently bonded or oxyanions like MnO_4^- the permanganate ion which has Mn^{+7} (also called manganate VII ion)

Write down some examples of compounds with transition elements in variable oxidation states, start with +2 for each of them.

COMPLEX ION FORMATION

- Transition metal ions are small and positively charged – often with a large positive value \therefore they will attract species that are RICH IN ELECTRONS – called Ligands.
- **Ligands** are neutral molecules or negative ions that have NON-BONDING PAIRS OF ELECTRONS e.g. water, ammonia, chloride and cyanide ions.
Non-bonding pairs are also called **lone pairs** of electrons
- **Complex ions** form when the **non-bonding pair of electrons** on a **ligand** forms a **coordinate covalent bond** with a **transition metal ion**, e.g. hexaaquairon III ion – most transition metal ions exist as hexahydrated complex ions in aqueous solution.
- Examples of complexes:
 - Tetraamminecopper II ion (deep blue colour)
 - Silver diamine (colourless)
 - Tetrachlorocuprate II (yellow)
- **Coordination number** of a complex: the number of lone pairs bonded to the metal ion

COLOURED COMPLEXES

- Tetraamminecopper II is a blue solution because when (white) light shines on it, the red part of the spectrum is absorbed and the blue part of the spectrum is transmitted (reflected) back out.
- The wavelength that is absorbed depends on how the d sub level splits when ligands join (bond) to the transition metal ion.
- When 6 ligands bond to a transition metal ion an octahedral complex (that's the shape of it) forms – when this happens the 5 orbitals in the 3d sub level split with 3 orbitals at a slightly lower energy level than the other 2 orbitals.
- The energy that is absorbed is the amount needed to move an electron from one of the lower 3d split orbitals to one of the higher 3d split orbitals (we call this “promoting an electron”) – the energy being absorbed corresponds to a wavelength and the complementary wavelength to this one is reflected = colour we see.
- The size of the split determines the colour.
- Four factors that determine the size of the 3d sub-level split:
 - Nature of transition element $[\text{Mn}(\text{H}_2\text{O})_6]^{2+}$ pink $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ green
 - Oxidation state $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ green $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ yellow/brown
 - The type of ligand $[\text{Cu}(\text{H}_2\text{O})_4]^{2+}$ blue $[\text{Cu}(\text{NH}_3)_4]^{2+}$ deep blue $[\text{CuCl}_4]^{2-}$ yellow
 - The shape of the complex ion

CATALYTIC PROPERTIES

- **Definition:** increase the rate of a chemical reaction without being used up. They provide an alternative chemical pathway of lower activation energy.
 - **Heterogeneous:** the catalyst is in a different phase to the reactants and products
 - E.g. the catalyst might be a metal that adsorbs reactants onto the surface – providing a surface to align the reactants with the correct orientation to react easily – e.g. Ni or Pd in the hydrogenation of unsaturated carbon compounds.
 - Transition metals make good heterogeneous catalysts
 - E.g. Iron in the Haber Process (ammonia being made from hydrogen and nitrogen)
 - E.g. Rh, Pd & Pt in catalytic converters in automobiles (used to convert CO, nitrogen oxides and unburnt hydrocarbons into CO₂, N₂ and H₂O).
 - **Homogeneous:** the catalyst is in the same phase as the reactants and products.
 - The characteristic variable oxidation states of transition metals make them well suited as catalysts because the oxidation states of the transition metals often increase (loss of e) then decrease (gain of e) during the course of the reaction they are catalyzing.
 - i.e. the two reacting species may bond chemically to the transition metal to form an intermediate chemical where they react then leave.
 - **MnO₂** (manganese (IV) dioxide) catalyses the decomposition of H₂O₂ into O₂ and H₂O.
 - **V₂O₅** (vanadium (V) oxide) catalyses the reaction producing SO₃ from SO₂ in the Contact Process (production of sulfuric acid).
 - **Fe and Co** in biological catalysts – Co in vitamin B₁₂ which is vital in the production of red blood cells which are kind of critical if you want to keep living. Fe in haemoglobin, which carries oxygen in the blood, also kind of critical if you want to keep living.
- **The world economy and catalysts:** making chemical products more quickly and with less energy means these processes are more cost-effective and less damaging to the environment.
- **Green chemistry:** designing products and processes that reduce/eliminate the use/generation of hazardous substances.
- **Supply and Demand:** as demand for transition metals increases and demand for catalysts increases prices rise. E.g. ever wonder how many catalytic converters there are in the world? How many cars are there?